NASA-CR-200059

FINAL REPORT

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For National Aeronautics and Space Administration Proposal:

Development of a Model of Atmospheric Oxygen Variations
to Estimate Terrestrial Carbon Storage and Release

NAGW-3929

First year: 1 January 1993 to 31 December 1993
Second year: 1 May 1994 to 30 April 1995
No-cost extension: 1 May 1995 to 31 October 1995

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Introduction

We have completed two and a half years of work towards the development of a model of atmospheric oxygen variations on seasonal to decadal timescales. The findings of the first two years of work have been summarized in annual progress reports; here we summarize the work completed during the six months of the no-cost extension period. During this time, we completed the production of an oxygen climatology of the world ocean and analyzed, in a preliminary sense, the results.

Cleaning the data set

A scheme was developed to remove cruises of low quality from the data set by making comparisons with cruises of known high quality. This filtering procedure improved the quality of the data set considerably. Our objective mapping scheme, described in the last progress report, was then applied to these filtered data.

Analysis

Examination of the oxygen climatology revealed statistically significant annual cycles throughout the upper 500 m of the ocean. An annual harmonic was fitted to the data averaged over 12° latitude bands in each major ocean basin. Vertical trends in the phase and amplitude of the annual cycle were noted (Figure 1). The cycle in surface waters is characterized by a summer maximum and a winter minimum, a cycle consistent with high rates of photosynthesis and warming during the summer and cooling and entrainment of oxygen-depleted water during the winter. The phase of the annual cycle shifts abruptly at a depth between about 30 and 130 m. Just below this depth, the annual cycle is characterized by an early-spring maximum and a late-fall minimum, consistent with a cycle driven by respiration and replenishment of oxygen from the atmosphere by ventilation. We interpreted the depth of the abrupt phase shift as the compensation depth during summer. In middle latitudes above the summertime compensation depth, the amplitude increases and the maximum occurs later in the year with increasing depth. This trend was interpreted as the shallow oxygen maximum. Below the summertime compensation depth, the amplitude of the annual cycle generally decreases with depth, indicative of decreasing respiration and ventilation rates, or less seasonality in both processes.

Horizontal trends in the phase and amplitude of the annual cycle were also noted. It was found that the summertime compensation depth decreases towards the poles in both hemispheres and is generally greater in the southern hemisphere, patterns found to be consistent with estimates of the compensation depth based on the penetration of light in the water column (Figure 2). Also, the seasonal maximum in surface waters occurs later in the year towards higher latitudes, while the seasonal maximum below the summertime compensation depth occurs earlier at higher latitudes. These two trends create an increasing phase shift with latitude between waters above and below the summertime compensation depth. Longitudinal trends were noted in the North Atlantic and North Pacific: at all depths, the amplitude of the annual cycle increases towards the western parts of the basins, as might be expected considering that physical forcing has greater seasonal variability in the west.

Preliminary simulations of the annual oxygen cycle in the atmosphere of the southern hemisphere produced amplitudes lower than observed, suggesting a possible underestimation of the amplitude in the southern ocean due to the sparsity of data in this region. Analyses of the surface temperature with the same data density showed that the amplitude of the temperature cycle is only slightly underestimated, compared with a higher density data set (Figure 3). This suggests to us that the low density of oxygen observations in the southern hemisphere is not a severe problem for atmospheric oxygen simulations, and points to the importance of an additional unknown process affecting the amplitude of the annual oxygen cycle in the atmosphere of the southern hemisphere.

Remaining work

We have submitted a proposal to finish the work remaining in this project. This essentially entails running atmospheric oxygen simulations and comparing these to observations. In short, the following tasks must be done:

- Run the atmospheric transport model to determine the distribution of N_2.
- Run the atmospheric transport model to make a new estimate of the air-sea gas transfer velocity.
- Determine where there is a net flux of oxygen between the terrestrial biosphere and the atmosphere.

Figure Captions

Fig. 1. Amplitude (open circles) and phase (filled circles) of the annual cycle of the average oxygen anomaly in 12° latitude bands of the middle and high latitudes (poleward of 18°) of the North Atlantic ocean as a function of depth. Error bars on the amplitude are ±1 standard deviation of the fit. The phase is only plotted if the amplitude is significantly different from zero. Surface values were not corrected for pressure variations.

Fig. 2. Zonal mean summertime compensation depth computed using two different methods and plotted as a function of latitude. The symbols represent the compensation depth computed from the phase change with depth of the annual cycle of the oxygen anomaly. The lines represent the compensation depth computed from the light field and a compensation light intensity of 1 W m^{-2}.

Fig. 3. Amplitude of the annual harmonic of surface temperature as a function of latitude for two different data sets. Filled circles represent data from the sea surface temperature atlas of Shea *et al.* (1992) and the open circles represent data that have exactly the same temporal and spatial resolution as the oxygen anomaly in this study.

North Atlantic

FIG. 1.

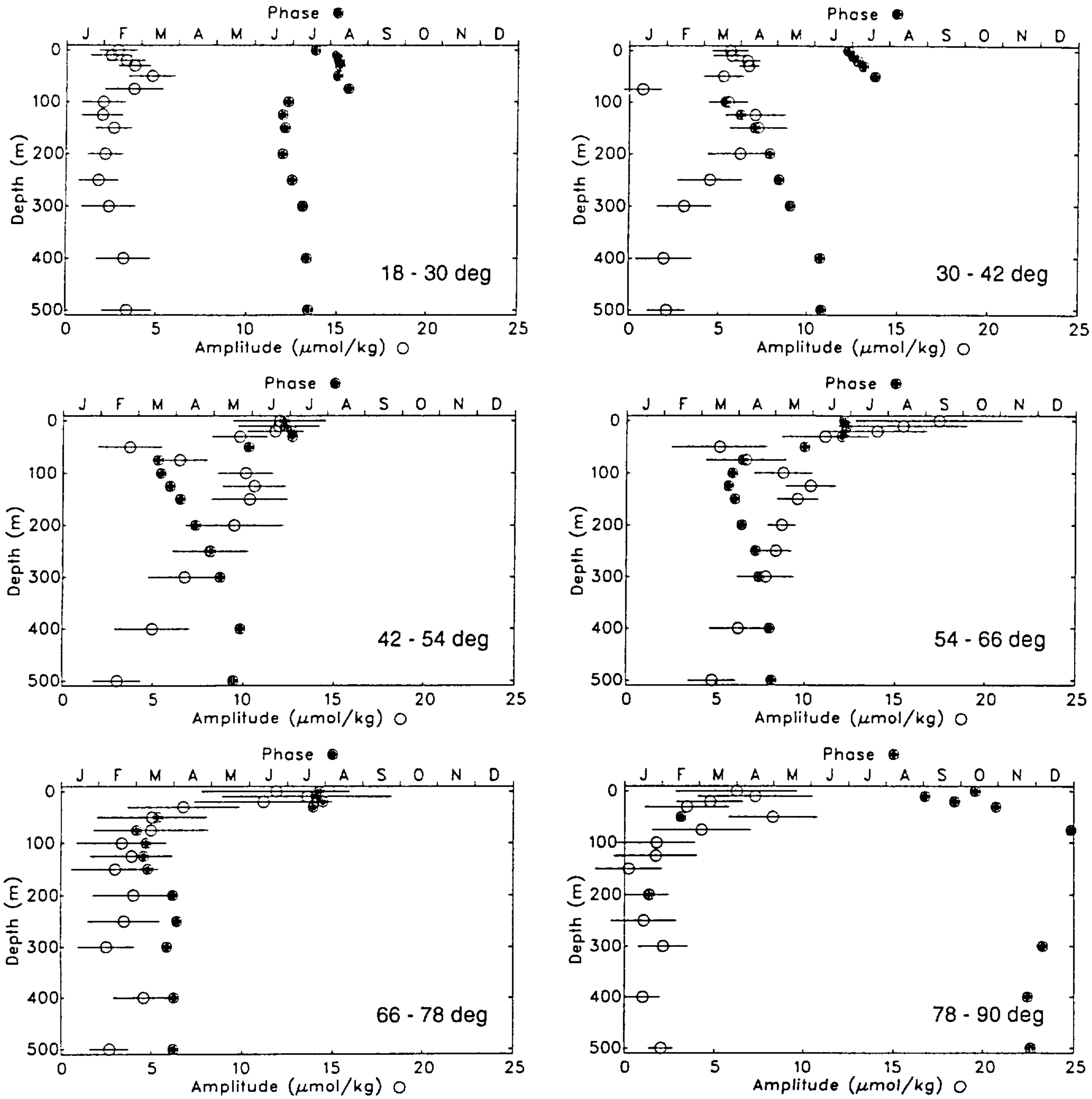
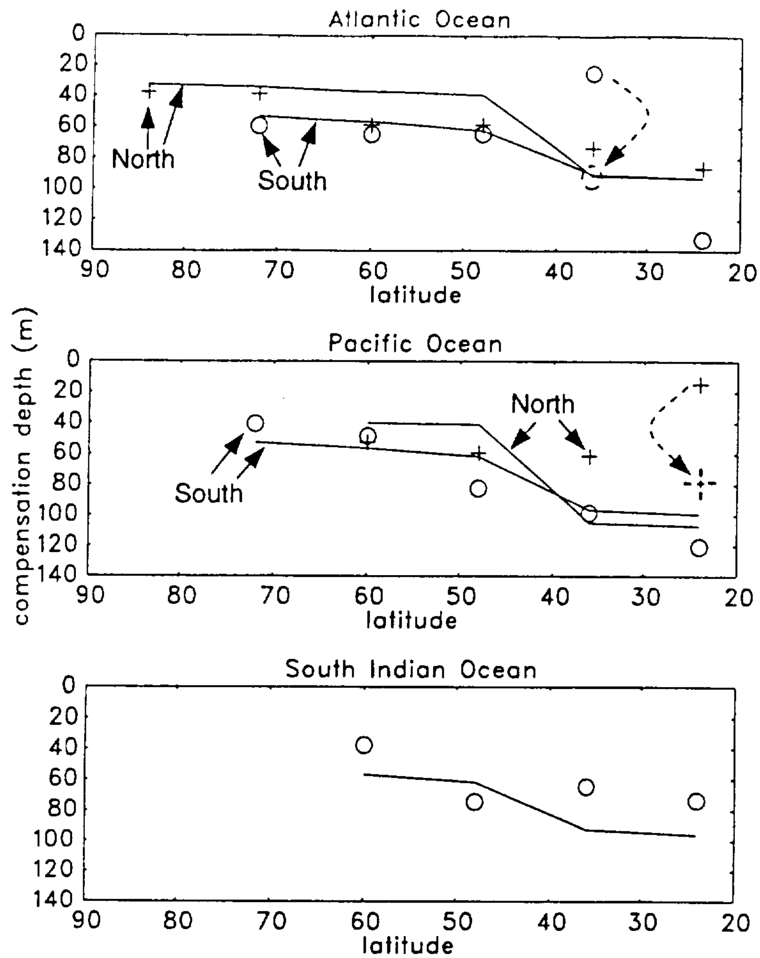
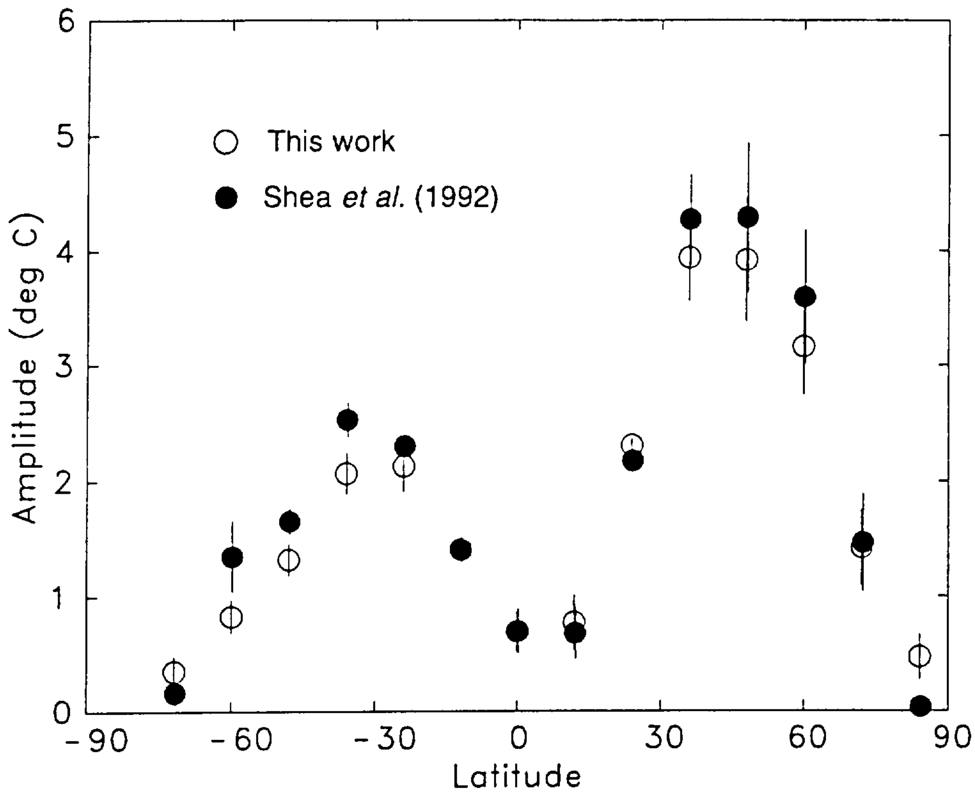


FIG. 2.



Atlantic Ocean
North
South
latitude
compensation depth (m)
Pacific Ocean
North
South
latitude
South Indian Ocean
latitude

FIG. 3.


Amplitude (deg C)
0
1
2
3
4
5
6
This work
Shea et al. (1992)
-90
-60
-30
0
30
60
90
Latitude